

Title of the Invention – The Voltage Dosimeter –
System and method for
supplying variable voltage
to an electric circuit.

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CROSS REFERENCES TO RELATED APPLICATIONS

001 Adolph Mondry – System and method for automatically maintaining a blood oxygenation level. P.N. 5,682,877, November 4, 1997 – herein referred to as 877. The flow sheets of that device are similar to those of the Voltage Dosimeter.

002 Meland Kantak – Internal fuel staging for improved fuel cell performance. P.N. application 20020081479 – herein referred to as 479. A similar device is used in the Voltage Dosimeter.

003 Thomas L Cable – High performance fuel cell interconnect with integrated flow paths and method for making same. P.N. application 200300877498 – herein referred to as 498. A similar device is used in the Voltage Dosimeter.

FEDERALLY SPONSORED RESEARCH GRANTS

004 There are no Federally sponsored research grants available to those involved in the research and development of this device.

BACKGROUND OF THIS INVENTION

005 Fuel cells and many devices that are voltage producing sources, such as solar cells, must constantly generate the full amount of voltage needed to operate all connected circuits. Connections between these devices will be needed as requirements expand. It is desirable to have a device available, which automatically controls circuit voltage to minimize the need for

constant voltage generation in fuel cells and other voltage producing devices without compromising circuit function, and which provides automatic switching.

BRIEF SUMMARY OF THE INVENTION

006 It is an object of the present invention to provide a method and apparatus to control voltage in fuel cells and other voltage producing sources to produce and deliver appropriate varying circuit voltage to decrease voltage production by placing the negative electrode of the voltage producing source in a predetermined range. It is a further object of this invention to provide automatic switching between these devices to provide extra voltage when needed.

007 In carrying out the above objects and other stated objects and features of the present invention a method and apparatus is provided as a Voltage Dosimeter for maintaining a desired voltage level at the negative electrode (herein named the entrance voltage) of a voltage producing source, and includes delivering a first voltage producing dose to the positive electrode (herein named the exit voltage) of the voltage producing source producing an exit voltage dose selected from one of a plurality of exit voltage doses between a first exit voltage dose and a second exit voltage dose. The method includes delivering a second voltage producing dose to the circuit while repeatedly sequencing through the plurality of sequential exit

voltage doses beginning with the first exit voltage dose and proceeding to an adjacent exit voltage dose in the sequence after a predetermined time interval has elapsed. The second voltage producing dose is delivered until the entrance voltage level attains the desirable level, at which point corresponding exit voltage and voltage producing doses are selected from the plurality of sequential voltage producing and exit voltage doses. The method also includes delivering the selected exit voltage and voltage producing doses so as to maintain the desired entrance voltage level.

008 In the preferred embodiment the method and apparatus automatically selects an appropriate reactive gas dose to maintain a desired entrance voltage level of a fuel cell, for which the system is particularly suited, and is the preferred voltage producing source, and includes delivering a first reactive gas flow rate to the fuel cell, producing an exit voltage dose in the fuel cell selected from one of a plurality of exit voltage doses between a first exit voltage dose and a second exit voltage dose. The method includes delivering the second reactive gas flow rate to the fuel cell while repeatedly sequencing through the plurality of sequential exit voltage doses beginning with the first exit voltage dose and proceeding to an adjacent exit voltage dose in the sequence after a predetermined time interval has elapsed. The second reactive gas flow rate is delivered until the entrance voltage attains the desirable level, at which point a corresponding exit voltage dose and

reactive gas flow rate are selected from the plurality of sequential exit voltage doses and reactive gas flow rates. The method also includes delivering the selected exit voltage dose and the reactive gas flow rate so as to maintain the desired entrance voltage level.

009 The advantages of the Voltage Dosimeter are minimal needs for constant voltage production in fuel cells and other voltage producing sources, the availability of switching voltage between these devices as the need arises, and a reduction in the cost of electricity.

010 The above objects, features, and other advantages will be readily appreciated by one of ordinary skill in the art from the following detailed description of the best mode for carrying out the invention, when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

011 Fig. 1/6 demonstrates a perspective view of the first embodiment of the present invention.

012 Fig. 2/6 is a graphical demonstration of the flow charts of the Voltage Dosimeter.

013 Fig. 3/3-5/6 are flow charts dealing with the voltage and reactive gas strategy of the present invention for use in the Voltage Dosimeter.

014 Fig. 6/6 is a flow chart for relating parameters in the Voltage Dosimeter.

DETAILED DESCRIPTION OF THE INVENTION

015 Referring now to Fig. 1/6, a first embodiment of the present invention is shown. This embodiment indicated by reference number **1** in Fig. 1/6 is the best mode in implementing this invention and is particularly suited for use as a Voltage Dosimeter. Figure 1/6 includes two voltmeters **2** and **3** - one volometer **2**, which measures exit voltage - v_1 - at the positive electrode **4** of a voltage delivery system and a second voltmeter **3**, which measures entrance voltage - v_2 - at the negative electrode **5** of a voltage delivery system. Two band pass electrical filters **7** and **8** are connected to each voltmeter **2** and **3**, then to an electronic control unit (ECU) **9**, which exercises control strategy, and processing and analyzing voltage data to maintain v_2 in a specific range. The ECU **9** preferably operates on power delivered from either D.C. or A.C. power supplies allowing portability to the Voltage Dosimeter System.

016 With continuing reference to Fig. 1/6 a fuel cell **10** as described in U.S. patent application 498 is added as the preferred embodiment of a voltage delivery system. The two reactive gas flow rates at the inlets **11** are controlled by two ECU **9** controlled variably opening solenoid valves **12** with Coulomb controlling circuits, as was taught in 877 and United States P. N. 5,008,773. Reactive gases pass through an electrolyte solution **13**, then react at the electrodes **14**. A typical reaction is $2H_2 + O_2 = 2H_2O + 4e^- + \text{heat}$, thus producing voltage in an electric wire **15** with resistance **16**. A circuit **6**, such as that of a

family dwelling, is pictured. Adequate voltage delivery here is the object of the present embodiment. A battery 17 is supplied for use when extra power is needed. Optional DC/AC converters 17 and AC//DC converters 6 are included for better use of conventional appliances.

017 Referring now to Fig. 2/6, the method of device function is demonstrated graphically. Voltage is placed on the ordinate and time, reactive gas flow rate, and voltage producing dosage are placed on the abscissa of a Cartesian plane. Maximum reactive gas flow rate or voltage producing dosage occurs at t_r on the abscissa, the significance of which will be presented later. Measured and calculated logarithmic functions are used in the preferred embodiment as exit voltage doses, but any measured and estimated transcendental function with an inverse may be used.

018 Referring again to Fig. 1/6, as will be seen, conditions on v_2 – the entrance voltage - control reactive gas flow rate 11 and thus v_1 - exit voltage, circuit voltage, circuit voltage dosage, and finally entrance voltage – v_2 – itself.

019 Referring now to Fig. 2/6, the illustrated method of reactive gas flow rate and exit voltage dosage selection starts with the administration of an extreme reactive gas flow rate – herein referred to as the selector dose of the reactive gas flow rate which produces the maximum or minimum voltage producing and exit voltage dose at the positive electrode of the fuel cell or of

any voltage producing device – as in curve A or B. Curve A is represented by $y = \log$ to the base a of x . Curve A activates at $x=0$.

020 Line CG is the desired voltage of v_2 – herein referred to as the selection parameter, which is a range in the actual device. At the intersection of line CG and curve A or B (call it X), line D points to point E on the abscissa as the selected reactive gas flow rate or voltage producing dose. This is determined by graphical means and, as will be seen, the flow charts. The virtual exit voltage dose logarithm is curve F, which activates at point E, the selected voltage producing dose, and is boosted by curves A, B, H – an overshoot of curve A – and curve I – a deactivation of curve H – to produce line G, which is the selected exit voltage dose and here is an exit voltage as well, because it is a horizontal line, and is represented by $y = \log$ to the base b of t_r , where t_r is the t value of the flattening out of the logarithm $y = \log$ to the base b of t (curve F) at t_r seconds. Line G is completely determined by the intersection (X) described above and in the flow charts, as will be seen, thus the determination of lines F and G by the above methods is unnecessary. Curve F and G start in the x coordinate system at $x=t$ and in the t coordinate system at $t=0$, when curve A deactivates. Curve F and G deactivate when curve A activates. Curve J is the virtual curve of curves A and H. K marks the Circulation time. It marks the time from the initial reactive gas flow rate to the first recording of v_1 . Its accuracy is essential for

proper flow chart function with respect to time. Its calculation and that of t_r will be demonstrated. The voltage producing dose is circulation time dependent. The exit voltage dose is not, since it is a function of time. At line CG v_1 usually differs from v_2 in value. At the above mentioned intersection (X) v_2 is in its desired range and v_1 is selected as the selected exit voltage dosage, which determines the selected voltage producing dosage. Until the above intersection (X) the line CG can not be placed on the Cartesian plane.

021 Before describing the flow charts it is useful to explain the terminology employed. The most recent base state keeps v_2 (the entrance voltage) in its desirable range. V_1 (the exit voltage) and v_2 are measured in all states. The washout state washes out overshoots. It also determines the voltage producing dose or in the fuel cell the reactive gas flow rate, as will be seen. For the fuel cell Voltage Dosimeter exit voltage doses are functions of reactive gas flow rates. For other voltage producing devices, exit voltage doses are functions of other voltage producing dosage mechanisms - motion, magnetism, heat or technologies producing heat.

022 Referring now to Fig. 3/6-5/6, flow charts are shown, which illustrate the system and method for the proper selection of exit voltage doses, voltage producing doses, and reactive gas flow rates.

023 Referring to Fig. 3/6, Step 400 determines various system parameters, which may be predetermined and stored in memory, calculated by an ECU

(such as ECU 9 in Fig. 1/6) or entered by a system operator. The system parameters include the following:

MIN R=minimum dose of voltage production and exit voltage given for each range.

MAX R=maximum dose of voltage production and exit voltage given for each range.

V1=exit voltage.

V2=entrance voltage. When it equals zero for ten seconds, the device deactivates and reactivates when the battery discharges in response to the closing of a circuit switch.

Tv1=desired exit voltage.

dL=low v2 threshold.

dH=high v2 threshold.

TSS=series state delay time.

Tcirc=circulation delay time.

Twash=washout delay time.

TR=desired response time or reaction time

To calculate dH and dL close all circuits. Increase v1 until all circuits first function properly. Measure v2. This is dL. Do the same with the smallest circuit. This is dH.

024 As shown in Figure 3/6 the ECU now passes control to Step **402**, which measures v_1 and v_2 . At Step **404** a maximum exit voltage and voltage producing dose of the last range is administered. This is represented graphically by curve A of Figure 2/6 and is called the selector dose. It represents the maximum exit voltage dose. The possible exit voltage dose is set for the lowest dose of the lowest range.

025 With continuing reference to Figure 3/6 at Step **406** v_1 is maintained while pausing T_{circ} seconds, then x is set to 0 seconds. Step **406** is called an adjustment state. It coordinates the flow charts with respect to time. Initial circulation times may be estimated or measured.

026 Referring once again to Figure 3/6 the ECU passes control to Step **408**, which continues to deliver exit voltage to v_1 . Step **408** is referred to as a series state - T_{ss} – and is necessary to coordinate the progression through various possible doses within a time period determined by t_r . The calculation of T_{ss} depends on the current operating state. Some representative calculations are illustrated in Figure 6/6 for a single ranged implementation as discussed in greater detail below.

027 Still referring to Figure 3/6 a test is performed at Steps **409** and **410**. It asks – is v_2 greater than d_H ? – and, is v_2 less than d_L ?, respectively. They split control into three pathways. Negative answers to both conditions direct control to Step **426**, where 1. The definitive current exit voltage dose is set

to the possible dose, while the preliminary voltage producing dose is set one circulation time into the future. 2. A pause for the circulation time takes place. Then, 3. t is set to 0. This represents preliminary voltage producing dose and definitive exit voltage dose selection.

028 Now referring to Figure 4/6 processing continues with the ECU directing control to Step 428, which pauses to washout high valued functions from the selected dose. The state is completed when all involved functions equal a straight line – the selected exit voltage dose. For convenience in the representation of the method in the flow charts the ECU was represented to set $t=0$ in Step 426. This actually occurs at the start of the washout state. The ECU directs in the washout state the determination of the selected value of point E of Figure 1/6 – the definitive selected voltage producing dose or the selected reactive gas flow rate in the case of the fuel cell Voltage Dosimeter – then activates these doses. The exit voltage dose remains the selected dose as curve G in Figure 1/6. Both of the above dosages continue until activation of MIN R or MAX R. Figure 430 measures voltage values for the Conditions below. Steps 409 and 410 represent a second test and ask the same questions as the above mentioned first test – Is v_2 greater than dH or less than dL , respectively? If either answer yes, control is directed to Steps 431 and 434, respectively, where a predetermined fraction of t_r is either subtracted or added, respectively to t_r . This pathway determines t_r

only if the circulation time is correct. The circulation time is calculated by keeping the last three base state values in memory. When control is directed to or beyond a noncontiguous base state from which control was originally assumed a predetermined amount of time is added to the circulation time. This will correct abnormally short circulation times. For abnormally long circulation times – if control passes consecutively to two ascending or descending base states, a predetermined amount of time is subtracted from the circulation time.

029 Referring now to Figure 5/6, if both conditions in the second test answer no, the ECU places control in Step **436**, the base state. Steps **438** and **440** represent the third test and ask the same questions (is $v_2 > dH$ or $< dL$?) as those of the previous tests with different consequences. They determine the stability of the base state (both conditions answer no if it is stable). If it is unstable, the ECU directs control to either Step **463**, if Step **438** answers yes, or **446**, which 1. Minimizes or maximizes the current dose, respectively 2. Pauses for the circulation time, then 3. sets $x=0$. These doses continue until dose selection. It should be noted that Steps **431**, **434**, the yes part of **418**, and the no part of Steps **433** and **440** all yield control to Step **436**, the base state. The ECU then directs control from Step **463** to Step **411**, and from Step **446** to Step **412**.

030 Referring again to Figure 3/6, the ECU directs control from Step 464 (evaluated later), and if Step 414 in Figure 4/6 (the first condition of fourth test to be elucidated soon) answers no, to Step 408 to maintain the current exit voltage dose for Tss. Control is then directed to Step 409, which, if along with Step 410 - the first test – the answer is yes to both conditions, control is passed to Steps 411 and 412, respectively, which decrement and increment the possible dose, respectively, then both pass control to Condition 414.

031 Referring now to Figure 4/6, Steps 414 and 418 represent the fourth and final test with different conditions than the other tests. These conditions ask if the present possible dose is the last dose available, and if the present range is the last one available, respectively. If Step 414 answers no, control is directed by the ECU to Step 408 in Figure 3/6, which maintains a current dose for Tss. If the condition answers yes, control is directed to Step 418, which determines if the present range is the last range available. If it answers no, control is directed to Step 464, in which control enters a new range, sets the current exit voltage and voltage producing dose to MAX R or MIN R of the new range, pauses for the circulation time, then sets $x=0$. Control is then directed to Step 408, which maintains a current exit voltage dose for Tss. If Step 418 answers yes, the ECU directs control to Step 436, the base state.

032 Referring now to Figure 6/6 a flow chart is shown illustrating representative calculations of Tss according to the present invention. One of these calculations or an analogous calculation is performed for each series state of Figure 3/6-5/6, such as illustrated at Steps 408, 411, and 412.

033 Returning to Figure 6/6 at Step 480 a test is performed to determine if the system has reached a base state. If not, the series state delay is estimated as: $Tss=tr/IR$. If the result is true, the process continues with Step 484, where a test is performed to determine whether $v2 < dL$. If true, then Step 486 determines whether the most recent base state is a minimum for the current range. If it is true, the series state delay is calculated by Step 488 as $Tss=tr/(IR-1)$. Step 498 then returns control to the series state which initiated the calculation.

034 With continuing reference to Figure 6/6, if the test at Step 486 is true, then the series state delay is calculated by Step 490 as $Tss=tr(MAX R-MIN R)/(IR-1)(MAX R-BASE STATE)$ before control is released to the series state via Step 498. If the test performed at Step 484 is false, then Step 492 performs a test to determine if the most recent base state is the maximum for the current range. If the result of Step 492 is true, then Step 496 calculates the series state delay as $Tss=tr/(IR-1)$. Control is then returned to the appropriate series state via Step 498. If the result of the test at Step 492 is false, then the series state delay is calculated by Step 494 as $Tss=tr(MAX R-$